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INVESTIGATING WASTE OIL DISPOSAL BY DIRECT
INCINERATION

Maurice E. LePara, et al

Army Mobility Equipment Research and Development
Center
Fort Belvoir, Virginia

February 1975

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22. ABSTRACT (Continue on reverse side if necessary and identify by block number) A second combustion-emissions test program was conducted at Aberdeen Proving Ground, Maryland, to address the feasibility for disposal of waste oil products by direct incineration. A "referee" waste oil, composed primarily of automotive crankcase drains, was blended into No. 2 Fuel Oil and combusted in a burner-boiler powerplant located at the messhall facility. During this steady-state combustion, the stack emissions were monitored by the U.S. Army Environmental Hygiene Agency to define the effects of the waste oil fraction on particulate emission (continued)		

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rates. It was noted that particulate emissions increased significantly with the addition of the waste oil component, and indications were given that waste oil stratification could be a problem.

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INVESTIGATING WASTE OIL DISPOSAL BY DIRECT INCINERATION

I. INTRODUCTION

1. **Background.** The Facilities Engineering Directorate at Aberdeen Proving Ground (APG), Maryland, initiated a program in 1968 to dispose of generated waste oil by blending with a No. 6 Fuel Oil (Federal Specification VV-F815C). Approximately 10,000 gallons of waste oil have been consumed each year in this manner at the main APG powerhouse facility. Since No. 6 Fuel Oil is a relatively viscous product, no problems were encountered with the waste oil disposal system. In August 1972, it was reported that APG would be changing from No. 6 to No. 2 Fuel Oil (Federal Specification VV-F815C) as a result of air pollution abatement legislation restricting the level of sulfur in the fuel. Because of the obvious difference in properties (other than sulfur content) between No. 2 and No. 6 Fuel Oil, this office became concerned that continuance of the waste oil disposal system could:

- cause stratification and/or sedimentation problems due to the difference in gravity (waste oil is generally higher than No. 2 Fuel Oil) leading to potential malfunctioning of the burner nozzles.
- create excessive stack emissions exceeding the air pollution standards either due to improper combustion (i.e., nozzle deposits) or from the composition/concentration of the waste product itself.

In April 1973, this office conducted an initial waste oil incineration program at the main powerhouse facility (Bldg. 345) at APG. The stack emissions, monitored by U.S. Army Environmental Hygiene Agency (AEHA) emissions specialists, were measured while No. 2 Fuel Oil and No. 2 Fuel Oil containing approximately 1% waste oil were burned.¹ In summary, there was no significant difference in the emissions levels between the neat fuel and the fuel adulterated with waste oil. Furthermore, the APG facility engineer reported that incineration of this mixture did not create any burner nozzle maintenance problems. There were, however, several shortcomings in this initial program. Since the mixing of the waste oil with the base fuel oil was extremely difficult to control, only an estimate of the percent of waste oil reaching the burner during the steady-state emissions test could be obtained. Also, the low concentration of waste oil may not have been a significant contaminant when compared to the tank-bottom residue of the No. 6 Fuel Oil remaining in the main storage tank from previous

¹ G. E. DeBono, "Investigating Waste Oil by Combustion," CCL Interim Report No. 3008, AD No. 772911, January 1974.

years. Finally, the introduced waste oil generated at APG was not considered to be representative of typical waste oils due to its unusual lightness (i.e., low viscosity, high API gravity, low ash, etc.). An analysis of this waste oil compared with other waste oils reported in the literature brings attention to this point (Table I). A review of the results of this initial emissions test, the physical arrangement of the burner-boiler system, and the atypical properties of the waste oil indicated the need for a second combustion-emissions program to establish baseline parameters for this waste oil disposal system. This report describes the results of the second combustion-emissions test conducted at APG.

Table I. Comparison of APG Waste Oil with Other Sources

Waste Oil Source/Reference	Kin. Vis. @ 100°F, D 445	°API Gravity, D 287	Water & Sediment, D 1796	Sulfur, % Wt., D 129	Total Ash, % Wt., D 482	Sulfated Ash, % Wt., D 874
APG ¹	7.34	32.0	1.4	0.24	0.50	
(2)	53.3	24.6	0.6	0.34		1.31
	57.7	26.0				1.30
	55.1	25.0		0.24	1.61	
(3)		26.7	4.8	0.26	0.40	
(4)	248	24.6	0.6			
	256	25.0			1.62	
	161	27.9	2.4		1.10	
		24.8	18.0		2.16	
(5)				0.44	1.43	1.69
Patuxent N.A.S. ¹	60.3	28.1	Trace	0.35	0.95	

¹ G. E. DeBono, "Investigating Waste Oil by Combustion," CCI Interim Report No. 30081, AD No. 772911, January 1974.

² Anonymous, "Final Report of the API Task Force on Used Oil Disposal," American Petroleum Institute, New York, N.Y., May 1970.

³ M. Liberman, "Combustion and Heat Recovery of Air Force Waste Petroleum Oils and Lubricants," Air Force Weapons Laboratory Report No. AFWL/TR-73-244, February 1974.

⁴ S. Chansky, W. McCoy, and N. Surprenant, "Waste: Automotive Lubricating Oil as a Municipal Incinerator Fuel," Environmental Protection Technology Series Report No. EPA/R2-73-293, September 1973.

⁵ G. A. Chappell, "Waste Oil Processing," Commonwealth of Massachusetts, Division of Water Pollution Control Publication No. 6722-31-100-4-73-CR, January 1973.

II. INVESTIGATION

2. Details of Test. The details of the test are as follows.

a. **Plant Facilities/Operation.** The powerplant system at the APG Messhall (Bldg. 4219) was selected for this second combustion-emissions test because the fuel-

system design offered a simple and accurate method for controlling the waste oil/fuel oil ratio. The burner system consisted of three five-tube, high-pressure boilers and three oil fired, low pressure, rotary-cup KEW ANEE burners. This system, originally designed to burn a No. 1 or a No. 5 Fuel Oil, was rated at 86.3 hp, 30,808.5 pounds of steam/hour, and 4,500,720 Btu. For this test, the fuel was to be metered directly to the burners from a 1200-gallon tank truck not only permitting accurate mixing of the desired fuel oil/waste oil ratio but also controlling delivery to the burners during the steady-state emissions test.

b. **Waste Oil Collection.** The waste oil used in this test was considerably heavier than that used in the previous test at the APG powerhouse.² To insure that a sufficiently "heavy product" was tested, the waste oil was collected in 55-gallon drums located at the main APG Post Exchange Service Station. It consisted almost entirely of drained crankcase oil from commercial-design vehicles with trace amounts of anti-freeze and hydraulic brake fluid and some transmission fluid. In addition, some water contamination occurred from improper drum covering and/or closure procedures since the drums were positioned outside. This water, after settling, was pumped out prior to the combustion-emissions test to insure that the water contaminant did not influence the resultant stack emissions. A comparison of the characteristics of this collected "referee-type" waste oil versus the waste oil used in the initial program is shown in Table 2.

Table 2. Comparison of APG Waste Oils

Source	Kin. Vis. @ 100°F. D 445	Gravity, ° API. D 287	Water & Sediment, D 1796	Sulfur % Wt. D 129	Total Ash, % Wt. D 482	Ramshotbottom Carbon Residue, D 524
Initial Combustion Test	7.34	32.0	1.1	0.21	0.50	0.89
Second Combustion Test	86.7	21.9	0.1	0.39	1.60	1.36

c. **Fuel and Stack Emission Sampling.** To assess the effect of this referee waste oil on combustion of No. 2 Fuel Oil, the AEHA again participated in monitoring stack emissions. As before, two series of emissions tests were required. The first series of tests was made while No. 2 Fuel Oil obtained from the 10,000-gallon underground storage tank located at the messhall facility was burned. Samples of this base fuel were obtained from the sampling valve adjacent to the burner system and from the underground storage tank prior to the baseline combustion-emissions test. Using this base

² G. E. DeBono, "Investigating Waste Oil by Combustion," CCL Intecom Report No. 3008, AD No. 772911, January 1974.

fuel, AEHA personnel monitored the stack emissions during three 2-hour runs. The details of the emissions stack sampling/analysis procedures performed by AEHA are presented in the Appendix.

The second series of combustion-emissions tests was made while the referee waste oil/fuel oil blend was burned. A 1200-gallon tank truck containing 200 gallons of waste oil and 800 gallons of No. 2 Fuel Oil served as the temporary mixing reservoir. The resultant blend was pumped to the burner system from the bottom of the tanker via tubing. The 200 gallons of referee waste oil, collected in four 55-gallon drums, was sampled prior to mixing to assess the variation in composition and the occurrence of stratification. To possibly avoid any stratification occurring within the tanker, the waste oil from the four drums was pumped into the tanker at different time intervals. Although this precaution was taken, it was anticipated that stratification could occur due to the wide differences in API gravity between the waste product and the No. 2 Fuel Oil. In view of this, the waste oil/No. 2 Fuel Oil mixture was sampled at three levels in the tank truck top, middle, and bottom prior to initiation of the steady-state emissions tests. With this 20% volume "nominal blend" of waste oil in No. 2 Fuel Oil being used, the second series of combustion-emissions tests was monitored by AEHA personnel during the three 2-hour runs. Details on the fuel oil samples, waste oil, and waste oil/fuel oil sample blends obtained during this second combustion-emissions test are provided in Table 3 with the analyses of the samples presented in Table 4. Accordingly, the emissions measured during this second combustion-emissions test by AEHA at the messhall facility are tabulated in Tables 5 and 6.

3. Results of Test. The analysis data on the "collected" waste oil samples indicated that stratification was occurring within the four drums. For that reason, the composite sample was taken (Sample No. 5, Table 5) to characterize the collected waste product. As noted, this composite waste consisted primarily of crankcase drains as evidenced by its high viscosity and low API gravity. After the 200 gallons of waste oil was introduced into the tank truck containing the 800 gallons of No. 2 Fuel Oil, the sample analysis indicated that satisfactory mixing had not occurred since the top, middle, and bottom samples (Samples 7, 8, and 9) revealed the waste product to be stratifying. Although the nominal concentration of waste oil was 20%, the fuel oil/waste oil blend was being fed to the burner system via a connection located at the bottom of the tanker. Because of this apparent stratification, the burner system was in fact combusting a fuel oil/waste oil blend of something in excess of the selected 20% volume ratio. Since the burner system was being fed primarily a "bottom sample" of fuel oil/waste oil during the three 2-hour runs of stack emissions measurements, the amount of waste oil in the No. 2 Fuel Oil for this "bottom sample" was determined by preparing known blends of waste oil in No. 2 Fuel Oil. The kinematic viscosity for each of these blends was determined and plotted on a graph (see Figure). From this graph, the concentration which corresponded to the viscosity of the bottom sample

(Sample No. 9) was interpolated and found to be 27%.

Table 3. Identification of Fuel Oil/Waste Oil Samples

Sample No	Date Sampled	Sample Type	Origin or Location	Sampling Depth	Sample Description
1	8/20/73	Waste Oil	Drum No. 4	Bottom	One of four drums of collected waste oil for combustion-emissions test.
2	8/20/73	Waste Oil	Drum No. 4	Top	Same as above.
3	8/20/73	Waste Oil	Drum No. 4	Bottom	One of four drums of collected waste oil for combustion-emissions test.
4	8/20/73	Waste Oil	Drum No. 4	Top	Same as above.
5	8/20/73	Waste Oil	Drums No. 1, 2, 3 & 4	Middle	This was a composite sample from all four drums of the collected waste oil.
6	9/24/73	No. 2 Fuel Oil	Fuel Line "A" Messhall		Fuel sample obtained prior to initial baseline emissions test at messhall.
7	9/27/73	No. 2 Fuel Oil	Tank Truck	Top of Fuel Tanker	Sample taken from tanker containing 200 gallons waste oil and 800 gallons fuel oil.
8	9/27/73	No. 2 Fuel Oil	Tank Truck	Middle of Fuel Tanker	Same as above.
9	9/27/73	No. 2 Fuel Oil	Tank Truck	Bottom of Fuel Tanker	Same as above.
10	7/20/73	No. 2 Fuel Oil	Contractor's Delivery Truck		Sample taken of No. 2 Fuel Oil delivered to messhall and other APG facilities.

Table 4. Inspection Properties of Fuel Oil and Waste Oil Samples

Sample Number	Kin. Vis. at 100°F. D 445	° API Gravity. D 287	Water & Sediment D 1796	Sulfur, % Wt. D 129	Total Ash, % Wt. D 482	Carbon Residue ¹ D 524	Distillation, °F, D 86			Aromatics, % Vol., D 1319
							10% Evap.	50% Evap.	90% Evap.	
1	83.3	23.9	1.9	—	1.55	3.74	—	—	—	—
2	72.2	25.6	Trace	—	1.90	4.04	—	—	—	—
3	86.8	25.1	0.05	—	2.15	4.16	—	—	—	—
4	84.1	25.8	0.02	—	1.95	3.97	—	—	—	—
5	86.7	24.9	0.10	0.39	1.60	4.36	—	—	—	—
6	3.15	33.8	Trace	0.20	Nil	0.38	450	518	610	32.1
7	3.58	35.7	0.90	—	0.20	0.88	—	—	—	—
8	3.65	32.4	1.40	—	0.30	0.95	—	—	—	—
9	6.16	30.6	0.50	0.35	0.65	1.49	—	—	—	—
10	2.80	34.6	Trace	0.23	Nil	0.35	426	502	596	29.3

¹ Although a 1.0-gram sample is specified for D 524 (Ramsbottom Carbon Residue), the presence of H₂O in some of the samples causes excessive scattering. As a result, the sample size for all samples was reduced to 1.0 gram.

Table 5. Combustion Emissions Results from APC Messhall (Bldg. 4219)

Test Parameter	Allowable or Legal Limit	Results Obtained	
		No. 2 Fuel Oil (No Waste Product)	No. 2 Fuel Oil + ~ 20% Waste Oil
Emissions Rate:			
GR/SCF ¹	² 0.03	0.047	0.262
lb/MBtu ³	0.6	0.031	0.158
lb/hour	—	0.184	0.938
Visible Emissions	No. 2 Max ⁴	0	0
Sulfur Content, % Wt	0.30	0.20	0.35
Trace Metal Emissions, GM/Day:			
Lead	—	3.86	172
Calcium	—	Nil	97
Zinc	—	1	410
Magnesium	—	Nil	37

¹ Corrected to 50% excess air, dry basis, 25°C., and 1 atmosphere.

² This limit, imposed by the State of Maryland, applies only to *residual oil burning* equipment.

³ As specified in AR 11-21, Environmental Pollution Abatement.

⁴ A maximum No. 2 rating on the Shell Bacharach Scale.

The net effect of this 27% waste oil on air pollution regulations was explained by AEHA in their emissions survey report.³ This was explained in the following manner:

- AR 11-21 Environmental Pollution Abatement limits emissions from boilers in Bldg. 4219 to 0.6 lb/MBtu.
- The State of Maryland Bureau of Air Quality Control limits smoke emissions from distillate-fired boilers to a No. 2 rating on the Shell Bacharach Smoke Scale. No visible emissions are allowed except during start-up, and the sulfur content of the fuel oil is limited to a maximum of 0.30% wt. *Residual oil burning* equipment is limited to 0.03 GR/SCF.

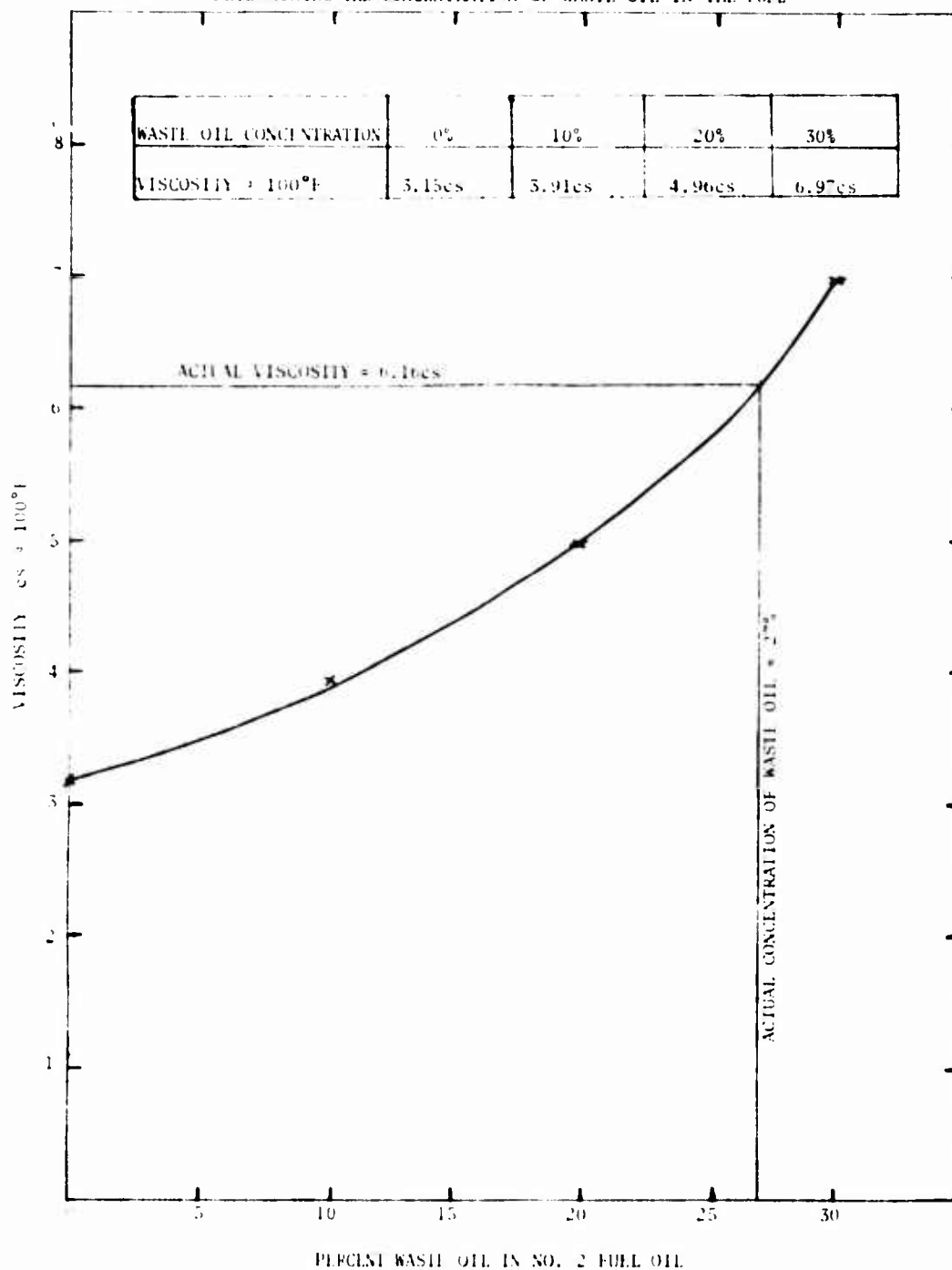
³ A. R. Paine and J. T. Higgins, "Air Pollution Engineering Special Study No. 21-015-73/74, Waste Oil Utilization Program, Aberdeen Proving Ground," April and September 1973.

Table 6. Stack Emissions Data from APC Messhall (Bldg 4219)

Test Details	Results Obtained					
	No. 2 Fuel Oil (No Waste Oil)			No. 2 Fuel Oil + ~ 20% Waste Oil		
Date:	24 Sep 73	24 Sep 73	24 Sep 73	27 Sep 73	27 Sep 73	27 Sep 73
Run Number:	1	2	3	4	5	6
Stack Gas Composition, % ¹						
CO ₂	4.8	4.9	4.8	4.9	4.7	4.1
O ₂	15.3	15.5	15.3	15.1	15.6	16.2
N ₂	79.9	79.6	79.9	80.0	79.7	79.7
Moisture	8	8	8	8	8	8
Excess Air	257	273	257	245	282	325
Stack Temperature, °F	443	444	448	444	435	426
Stack Velocity, m/sec	9.31	9.22	9.14	8.90	8.99	8.43
Flow, SCM ² sec	1.25	1.23	1.22	1.20	1.22	1.16
Sample Volume, SCM ²	2.75	2.75	2.78	2.55	2.63	2.49
Filter Catch, GM	0.0283	0.0101	0.0135	0.2485	0.2118	0.1617
Probe Catch, GM	0.0292	0.0327	0.0423	0.0522	0.0412	0.0448
Total Catch, GM	0.0575	0.0428	0.0558	0.3010	0.2530	0.2060
Concentration from filter, GM/SCM ²	0.0103	0.0037	0.0048	0.0974	0.0805	0.0649
Concentration from probe, GM/SCM ²	0.0106	0.0119	0.0152	0.0205	0.0157	0.0180
Total concentration, GM/SCM ²	0.0209	0.0156	0.0201	0.1180	0.0961	0.0829
Mass Rate from filter catch, lb/hour	0.1020	0.0361	0.0465	0.9270	0.7790	0.5980
Mass Rate from probe catch, lb/hour	0.1050	0.1160	0.1470	0.1950	0.1520	0.1660
Total Mass Rate, lb/hour	0.2070	0.1520	0.1940	1.1200	0.9310	0.7630

¹ Determined on a dry basis.² Standard conditions: 25°C and 1 ATM.

DETERMINING THE CONCENTRATION OF WASTE OIL IN THE FUEL



Determining the concentration of waste oil in the fuel.

In applying these limits to the initial combustion-emissions program wherein 1% waste oil was used at the main powerhouse facility (Bldg. 345), no violation of any emission standards occurred. However, in reviewing the results from this latter program in which 27% waste oil was consumed, there were indications that some emission standards were violated. More specifically, the sulfur content of the waste oil/fuel oil mixture was 0.35% (Note: a 0.30% maximum is permitted) and, more important, the particulate emissions rate was 0.262 GR/SCF. (Note: a 0.03 maximum rate is permitted.) This value is 773% greater than the maximum allowable rate and represents a fivefold increase over the baseline level. However, AEHA concluded that no emission levels were exceeded in this instance since there are no emission standards for No. 2 Fuel Oil. (Note: the 0.03 GR/SCF maximum applies to residual fuels only.) AEHA personnel maintained the position that a fuel oil/waste oil blend must be considered a distillate product if it meets the specification requirements given under Federal Specification VV-F815C, Fuel Oil, Burner. A tabulation of the inspection properties of this 27% waste oil/fuel oil blend versus the specification limits in VV-F815C is shown in Table 7. The Maryland Bureau of Air Quality (MBAQ) initially informed this office that a fuel could not be considered a distillate if it contains a non-distillate product such as waste oil. In view of this, their initial position was that the particulate emissions rate for the 27% waste oil blend was in violation of the MBAQ standards. However, in subsequent discussions between AEHA personnel and the MBAQ, tentative agreement was reached in favor of AEHA's conclusions. (Note: the problem of defining a distillate versus a residual fuel in terms of applying emission standards has been presented to ASTM D-2 Technical Committee E on Burner and Diesel Fuel Oils for an official ruling.)

The emission rates of the four trace metals analyzed showed a significant increase when the 27% waste oil was introduced. These increases were anticipated due to the nature of the "collected" waste product which had high concentrations of engine oil drains. To provide additional information on this point, samples of the products used in this combustion-emissions test and the previous program were analyzed for the four suspect metals: lead, zinc, calcium, and magnesium.⁴ The results of these analyses are shown in Table 8. Since neither AR 21-11 nor MBAQ provides emission standards for these or any trace metals, the obtained emission rates for all metals were not considered to be in violation although the rate for zinc was relatively high.

As mentioned in the AEHA report,⁵ the combustion-emissions test program was conducted on a short-term basis to observe whether significant increases in particulate emissions would be evidenced with the addition of the waste oil component. No

⁴ G. E. DeBono, "Investigating Waste Oil by Combustion," CCL Interim Report No. 3008, AD No. 77-2911, January 1974.

⁵ A. R. Paine and J. T. Higgins, "Air Pollution Engineering Special Study No. 21-015-73/74, Waste Oil Utilization Program, Aberdeen Proving Ground," April and September 1973.

Table 7. Properties of 27% Waste Oil Blend vs AA-F-3150. Limits

Characteristics	Sample #9 (27% Waste Oil in Fuel Oil)	Inspection Limits in AA-F-3150			
		No. 1 Fuel Oil	No. 2 Fuel Oil	No. 3 Fuel Oil (Light)	No. 4 Fuel Oil (Heavy)
Flash Point, °F	215	100 min.	100 min.	130 min.	130 min.
Pour Point, °F		0 max.	20 max.		150 min.
Water & Sediment	0.5	trace, max.	0.05 max.	1.00 max.	2.00 max.
Carbon Residue, 10% RTMS, %	11.19	0.15 max.	0.35 max.		
Ash, %	0.65			0.10 max.	0.10 max.
Distillation, °F:					
10% Evap.	399	120 max.			
90% Evap.		550 max.	540-640		
Kin. Viscosity, cSt, at 100°F	6.16	1.4-2.2	2.0-3.6	32-65	75-162
Gravity, °API	30.6	35 min.	30 min.		
Sulfur, % Wt	0.35	2 0.5	2 0.5	(3)	(3)

1 Carbon residue on 10% RTMS was obtained using a 1.0-gram sample instead of the required 1.0-gram sample.

2 Legal requirements may lower this value.

3 Legal requirements must be met.

Table 3. Metal Analysis of "Products" Used in Combustion Emissions Test

Sample Number	Type of Sample	Sample Obtained				Metals Present (ppm)		
		Initial Test a Bldg. 345	Second Test a Bldg. 4219	Lead	Zinc	Calcium	Magnesium	
-	Base No. 2 Fuel Oil	Yes	-	16.8	2.4	7.2	103	
-	Waste Oil	Yes	-	1121	355	317	42	
-	1% Waste Oil in No. 2 Fuel Oil	Yes	-	21.2	2.4	9.2	123	
<hr/>								
6	Base No. 2 Fuel Oil	-	Yes	50	30	50	5	
10	No. 2 Fuel Oil	-	Yes	54	11	54	5	
5	Waste Oil	-	Yes	6655	1331	1109	1008	
9	27% Waste Oil in No. 2 Fuel Oil	-	Yes	4934	518	399	379	

attempt was made to assess the potential deleterious effects of waste oil combustion on burner nozzles or heat-transfer surfaces of the boiler system. A previous study conducted for the State of Massachusetts revealed that attempts to combust 100% waste oil resulted in severe operating problems in a 50-hp Cleaver-Brooks boiler system.⁶ The results of the Massachusetts' study emphasized the need to remove or separate the inorganic ash materials from the waste product prior to combustion. More recently, under a USAF program addressing the feasibility of this approach, experimental combustion tests were performed using up to 10% waste oil in both No. 2 and No. 6 Fuel Oil.⁷ The results of the USAF program revealed no short-term air pollution effects or operational problems.

III. CONCLUSIONS

4. **Conclusions.** The two combustion-emissions programs conducted at APC demonstrated that waste oil can be incinerated as fuel-oil-blending components without attendant stack emissions problems. However, the use of the 27% waste oil/fuel oil blend in the KEWANEE burner system produced emission rates which could be in violation depending on whether the particular waste oil/fuel oil blend is defined as a residual or a distillate product. The high particulate emissions evidenced were in part attributable to the rather inefficient operation of the rotary-cup atomizers employed in the burner system. This important variable involving burner-boiler configurations can significantly affect and/or alter the emissions produced from the same waste oil/fuel oil mixture. It should be noted, however, that this combination of "heavy waste oil" and the burner system employing rotary-cup atomizers essentially represented a referee, or "worst case," situation. Other burner systems employing the steam-assist atomizers could be expected to produce substantially lower particulate emissions. This limited data acquired from these two combustion-emissions tests further supports the need for additional test programs to quantify the relationships between particulate emission rates, boiler-burner configuration and endurance, and long-term operation on waste oil/fuel oil blends to identify any potential burner nozzle and heat-transfer-surface problem areas.

⁶ G. A. Chappell, "Waste Oil Processing," Commonwealth of Massachusetts, Division of Water Pollution Control Publication No. 6722-41-100-473-CR, January 1973.

⁷ M. Liberman, "Combustion and Heat Recovery of Air Force Waste Petroleum Oils and Lubricants," Air Force Weapons Laboratory Report No. AFWL-TR-73-244, February 1974.

APPENDIX SAMPLING AND ANALYTICAL METHODS

1. Sampling Methods.

a. Particulates.

(1) The particulate train used consisted of a probe tip, heated stainless steel probe, glass cyclone, and glass fiber filter in a heated chamber; four Greenburg Smith impingers in an ice bath; vacuum pump; gas meter; and calibrated orifice.

(2) Isokinetic sampling conditions were maintained as close as possible by controlling pump vacuums in relation to pertinent system parameters so that the velocity of the gas entering the probe tip was equal to the velocity of the surrounding gas stream. The gas velocity was determined by use of an S type pitot tube. Temperature was measured with a chromel alumel thermocouple.

(3) The particulate was collected at several points across the stack diameter. Two diameters 90° apart were traversed. The number of sampling points was determined by the stack diameter and distance above and below flow disturbances. In this case, 10 points on each of two diameters were sampled for boilers in Bldgs. 345 and 4219.

b. Moisture. Moisture determination was made from the change in weight of the impinger containing silica gel and the change in liquid volume of the other three. Impingers 1 and 2 contained 100 ml of H_2O , impinger 3 was empty, and impinger 4 contained silica gel.

c. Gaseous Sampling. A Mylar bag sample was collected concurrently with each particulate sample. The sampling velocity was maintained proportional to stack gas velocity for the entire test.

2. Analytical Methods.

a. Particulates. Particulate determination was accomplished by measuring the weight change of the particulate traps in the system. The glass cyclone and the probe were washed with acetone. The washings were combined and dried to constant weight and a final weight was taken. An acetone blank was also included. The glass fiber filter was dried to constant weight in a desiccator and weighed. In accordance with ASME Power Test Code 27,* condensible particulates collected in the impingers were not included as particulate matter.

b. Moisture. Moisture content was determined by weighing four impingers before and after sampling.

c. Gases. A Fisher Hamilton Gas Partitioner was used to determine CO_2 , O_2 , N_2 , and CO in the Mylar bag samples.

* Power Test Code No. 27, "Determining Dust Concentration in a Gas Stream," adopted 29 April 1957, the American Society of Mechanical Engineers.